Open-System Adiabatic Quantum Annealing

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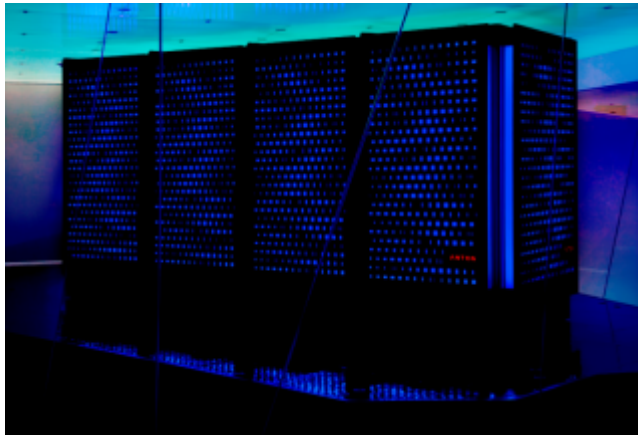
Need More Capability?

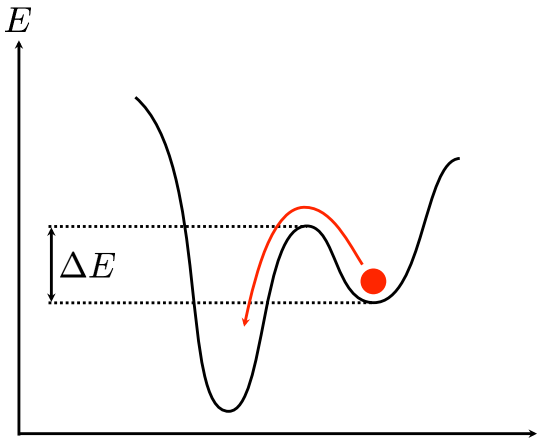
Exploit a New Phenomenon
D-Wave Quantum Annealer

Massive Scaling
Tianhe-2 (3M cores)



Application Specific Systems
D.E. Shaw Research Anton

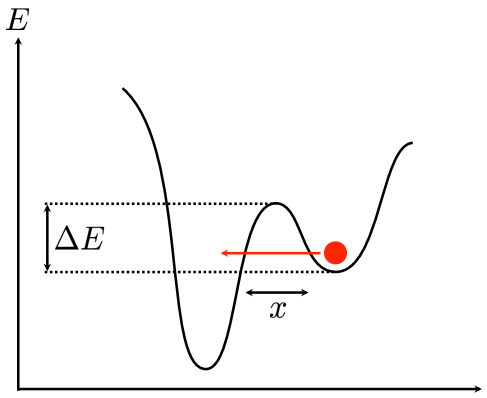
Quantum Annealing = Thermal Annealing ++



Probability to overcome barrier

$e^{-\beta \Delta E}$

$\beta \Delta E \begin{cases} \ll 1 \longrightarrow \text{easy to jump} \\ \gg 1 \longrightarrow \text{hard to jump} \end{cases}$



Probability to tunnel through barrier

$e^{-x\sqrt{\Delta E}}$

$x^2 \Delta E \begin{cases} \ll 1 \longrightarrow \text{easy to tunnel} \\ \gg 1 \longrightarrow \text{hard to tunnel} \end{cases}$

Adiabatic Quantum Annealing

Problem: find the ground state of

$$H_{\text{Ising}} = \sum_j h_j \sigma_j^z + \sum_{(i,j)\in E} J_{ij} \sigma_i^z \sigma_j^z$$

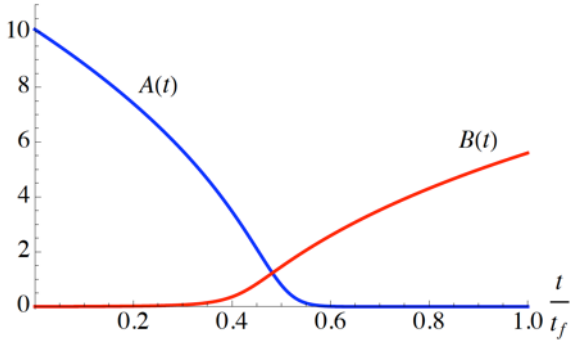
Shown by Barahona (1982) to be NP-hard in 2D, $J_{ij} = \pm$, $h_j \neq 0$.

Use adiabatic interpolation from transverse field (Farhi et al., 2000)

$$H(t) = A(t) \sum_j \sigma_j^x + B(t) H_{\text{Ising}}$$

$t \in [0, t_f]$

Program $\{h_i\}, \{J_{ij}\}$



Graph Embedding implemented on DW-1 via Chimera graph retains NP-hardness (V. Choi, 2010)

USC Research Foci

Quantum signatures

Is it behaving like an open-system, adiabatic quantum annealer?

Entanglement

Is it unambiguously a quantum machine?

Computational advantage

Is it faster, or better by some other metric?

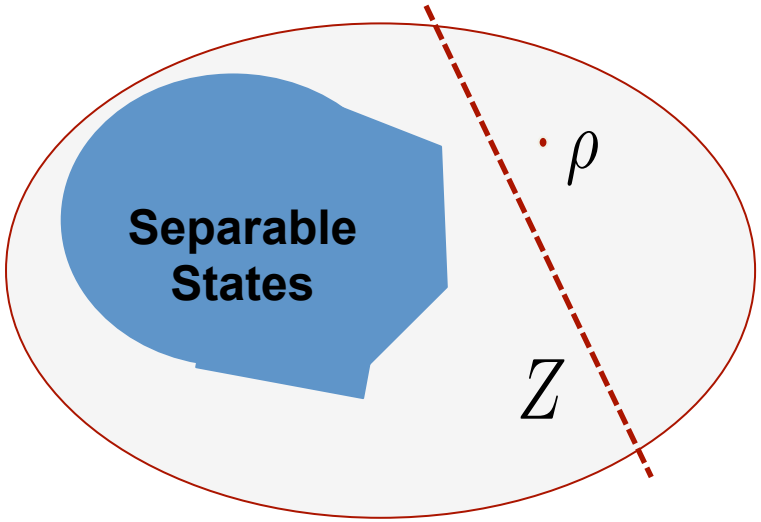
Applications

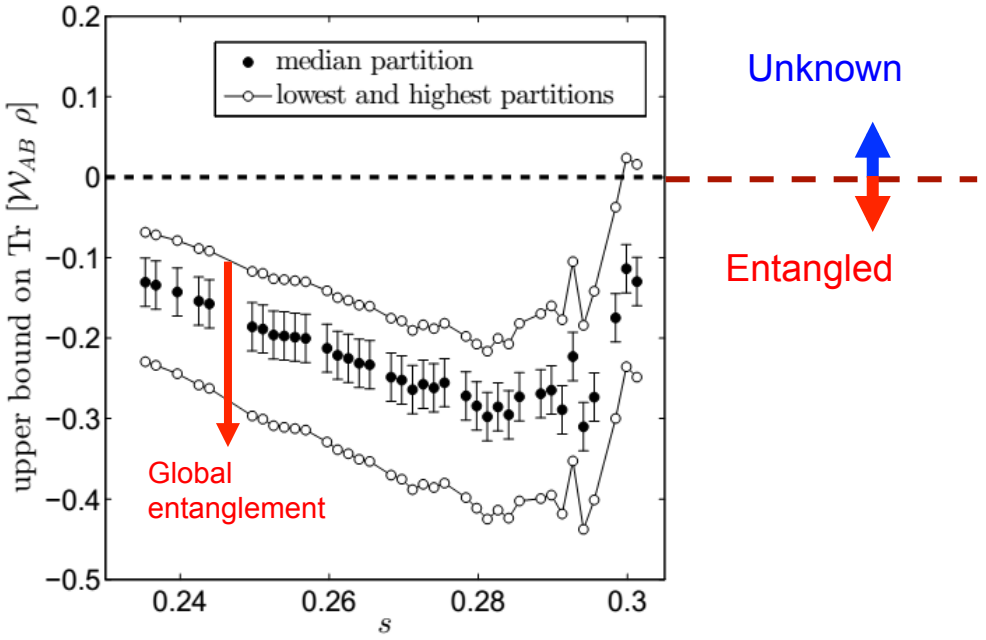
What human problems might it solve?

Witness for Entanglement

Collaboration with D-Wave

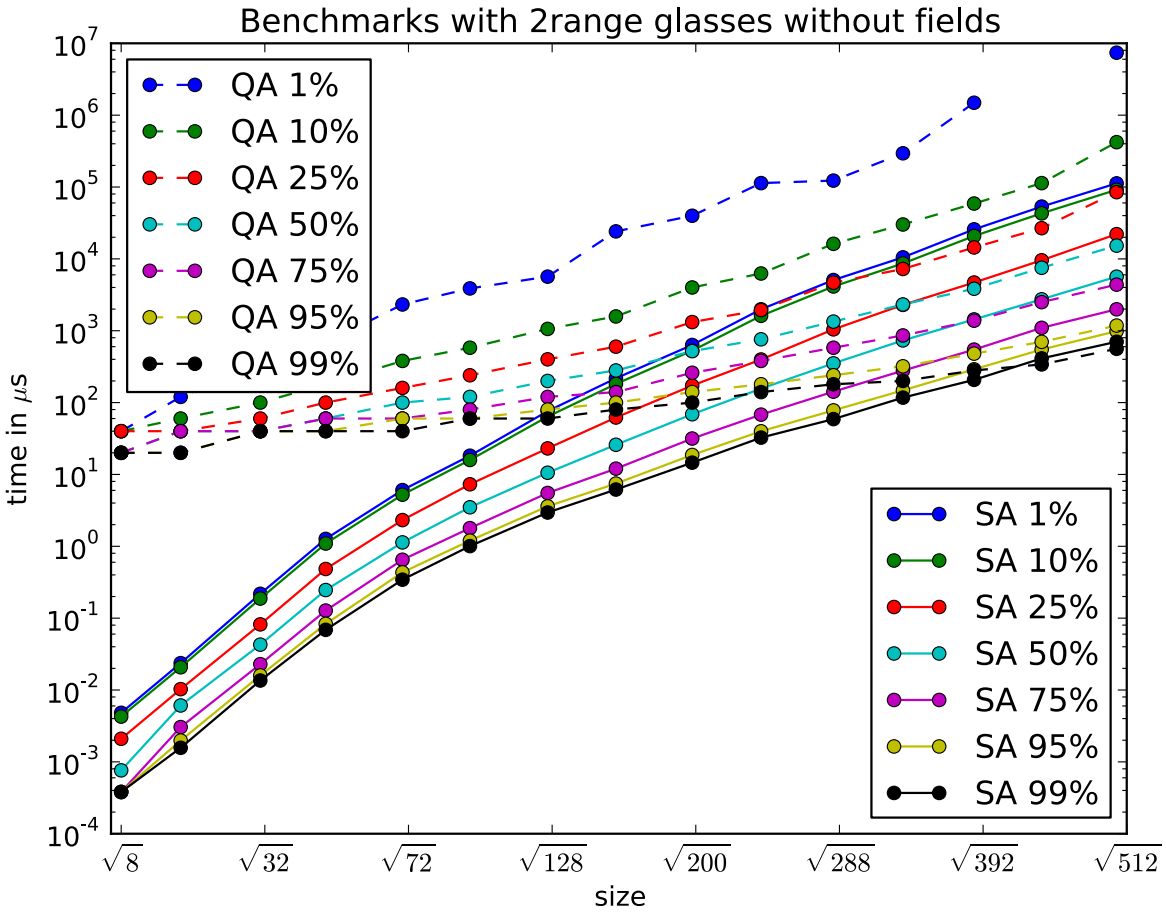
Only they can take the measurements needed





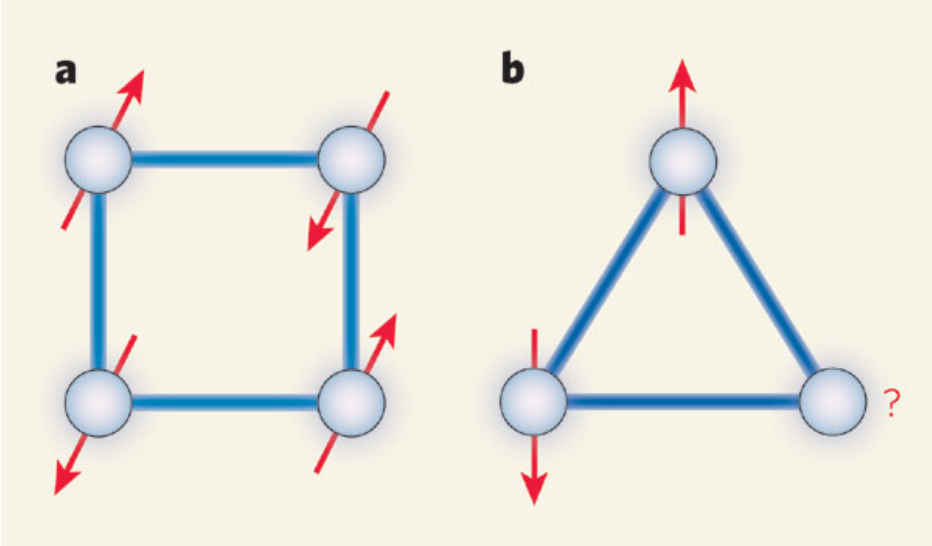
Lanting, et.al, PRX 4, 021001 2014

Quantum Annealing vs. Simulated Annealing



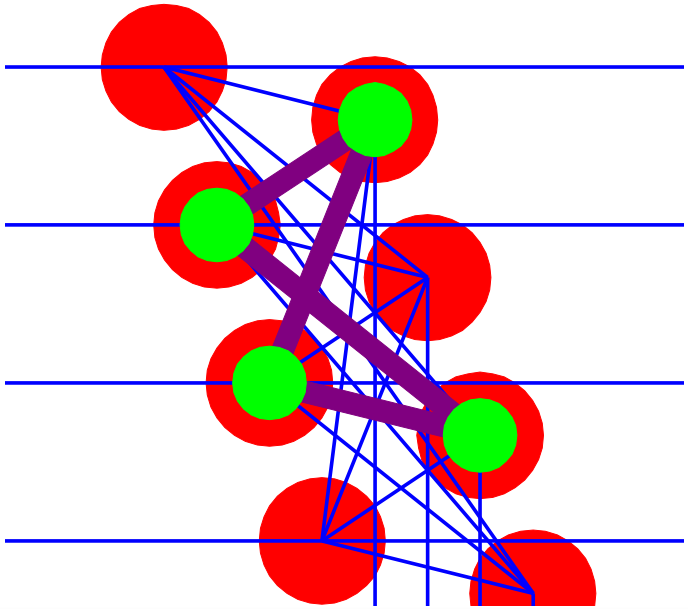
D-Wave 2 vs. Nvidia Kepler GPU (USC & ETH)

Hard problems motivated by satisfiability



Frustration

Random walk to create frustrated loops that respect a planted solution

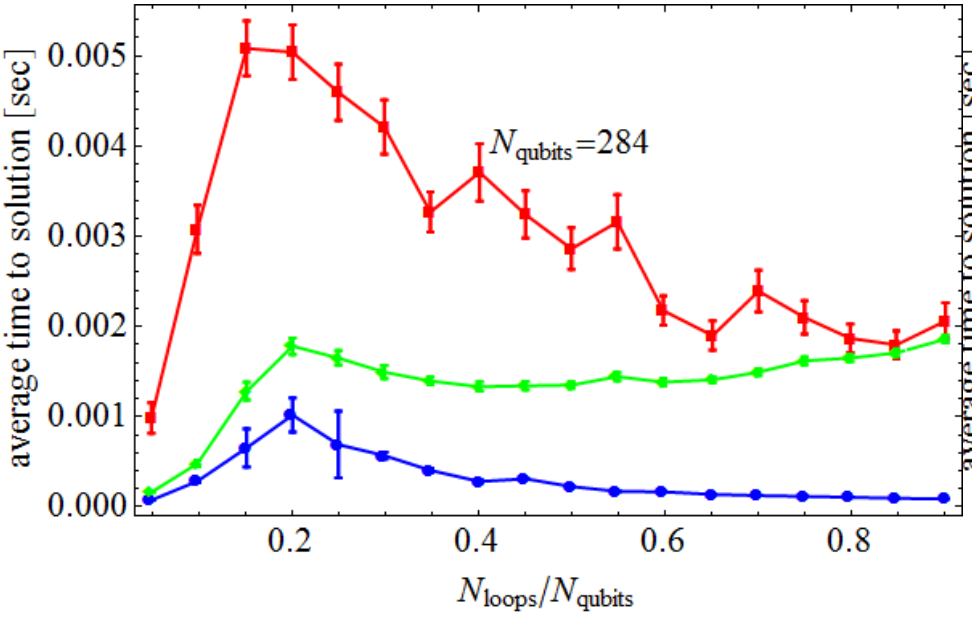


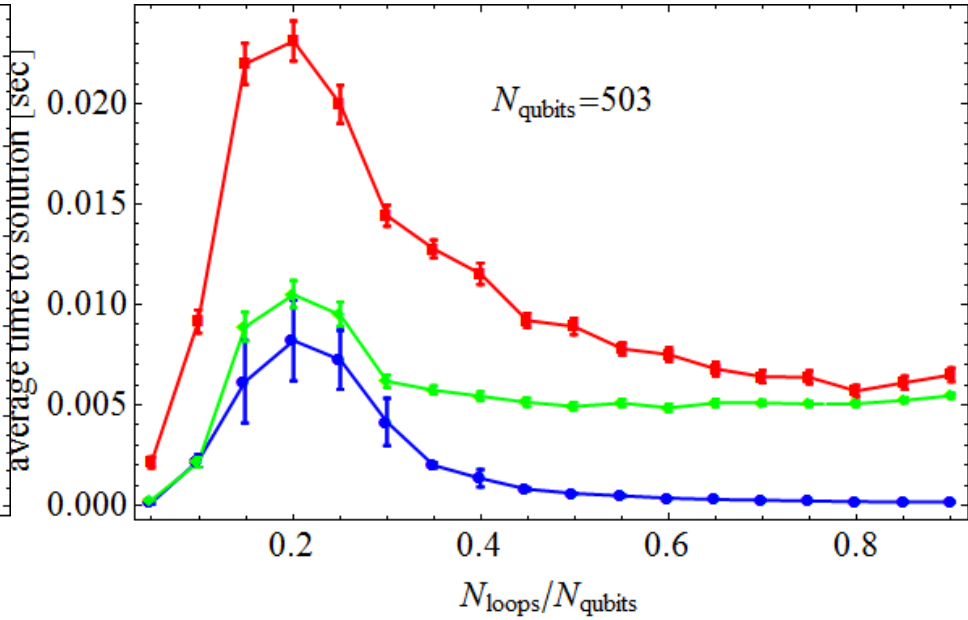
Itay Hen, Performance of D-Wave Two on Problems with Planted Solutions, AQC 2014

Hard problems for multiple heuristics

- "at least once with 99% chance"– a comparison.
- universal peak in hardness.

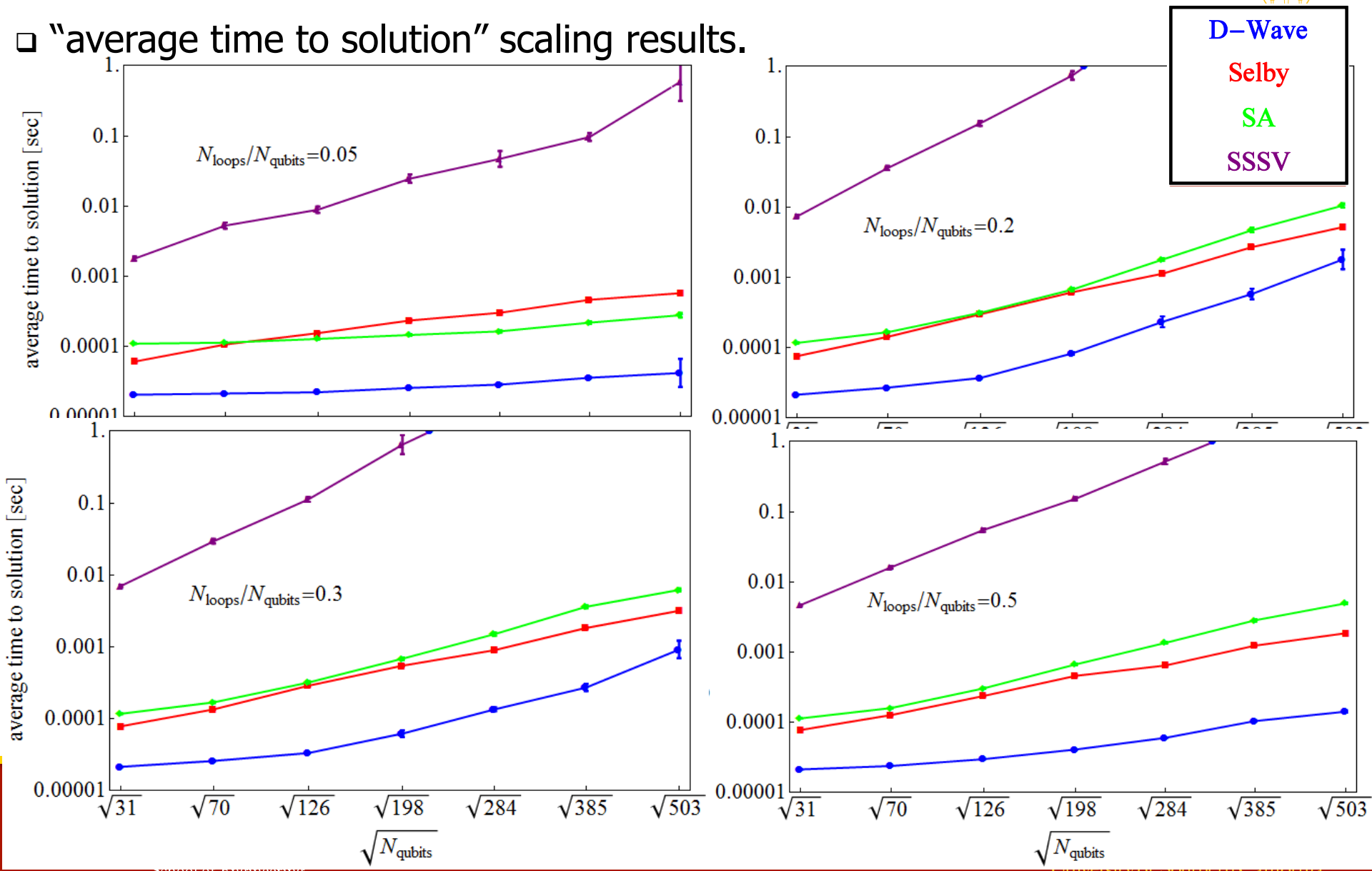
D–Wave
Selby
SA
SSSV



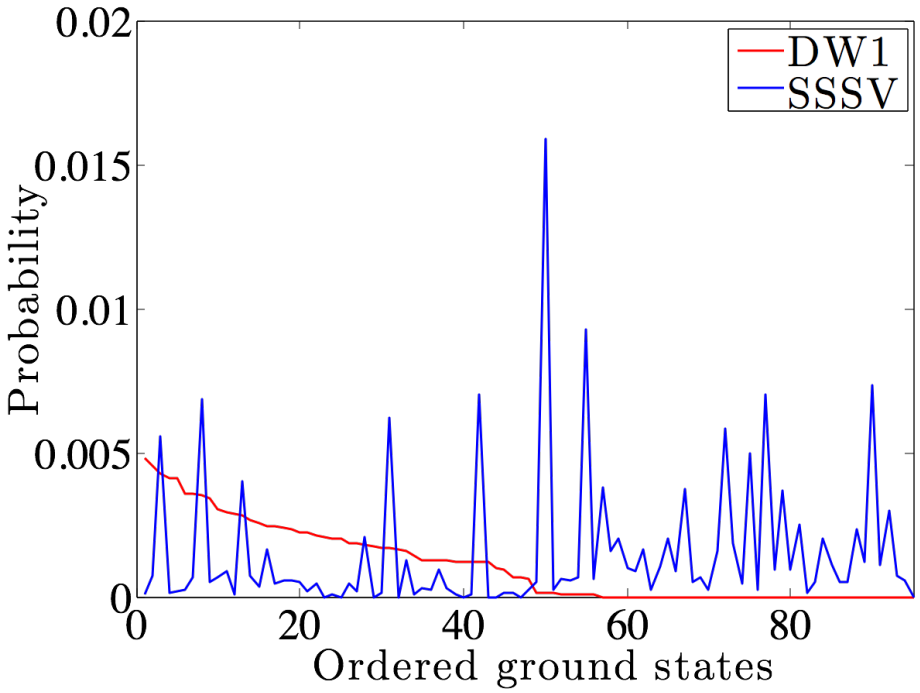


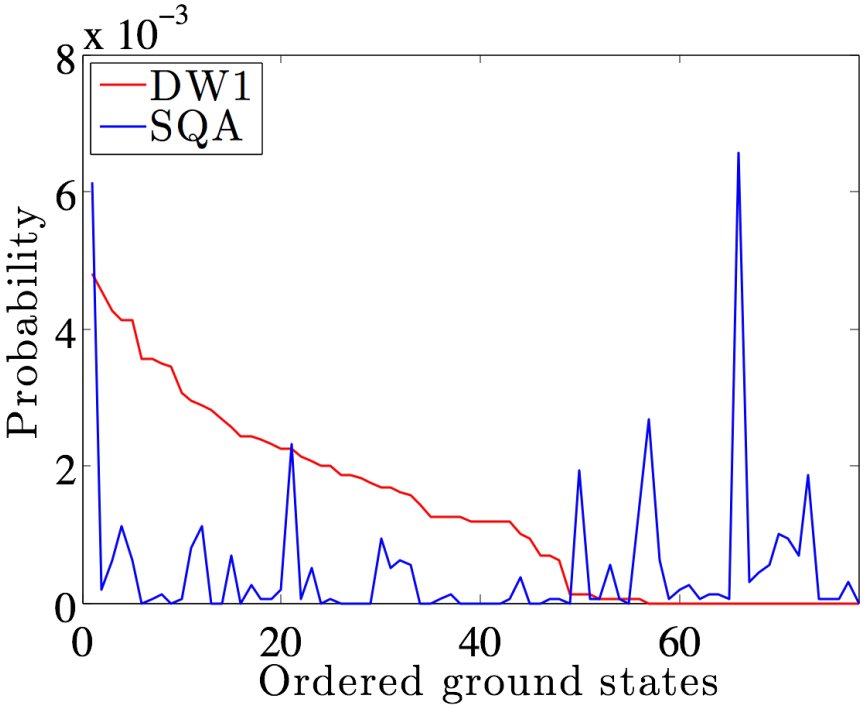
Performance on hard problems

- "average time to solution" scaling results.



Another Way to Add Value
Finding Different Solutions





Open Research Problems

Why does the D-Wave even work?

Its an open system

How much quantum speedup will there be?

Any? If so, on what problems?

What applications will it ultimately solve?

We've had half a century to find competing heuristics

How should you program it?

Specifically excluded from recent research programs

What should the topology be?

Reduce critical scaling limitation

Other adiabatic quantum systems will face these.

These questions are all bigger than just D-Wave